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DESIGN AND SIMULATION OF ACTIVE POWER FILTER FOR POWER QUALITY IMPROVEMENT

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ABSTRACT

The power electronic related facilities may generate a large amount of harmonic current due to the nonlinear input characteristic. The harmonic current may pollute the power system causing problems such as transformer overheating, rotary machine vibration, voltage quality degradation, destruction of electric power components, and malfunctioning of medical facilities. In order to solve the problem of harmonic pollution effectively, the harmonic current can be suppressed by using a passive or active power filter. Recently, the harmonic suppression facilities based on power electronic technique have been developed. These active harmonic suppression facilities known as active power filter can suppress the different order harmonic components of nonlinear loads.

This paper presents a comprehensive survey of active power filter (APF) control strategies put forward recently. It is aimed at providing a broad perspective on the status of APF control methods to researchers and application engineers dealing with harmonic suppression issues. Many control techniques have been designed, developed, and realized for active filters in recent years. Here we are proposing the Instanteous PQ theory methods is based on the theoretical analysis and simulation results obtained with MATLAB. Finally shunt active power filter is applied various load are balanced, unbalanced, variable loads.

KEYWORDS: Active Power Filter, Harmonic, Instantaneous P-Q Theory, Balanced, Unbalanced Loads, DC Link Voltage Controller, Voltage Source Inverter(VSC)

INTRODUCTION

In recent years, with the increase of nonlinear loads drawing non sinusoidal currents, power quality distortion has become a serious problem in electrical power systems. As nonlinear loads, these solid-state converters draw harmonic and reactive power components of current from ac mains. Conventionally passive L–C filters were used to reduce harmonics and capacitors were employed to improve the power factor of the ac loads.

The increased severity of power quality problems and other problems associated with the passive filters such as large size and weight, higher cost, fixed compensation, and resonance problems with loads and networks have required a focus on a power electronic solution, that is, active power filters (APF) as shown in Figure 1. In recent years, many publications [26-42] have also appeared on the harmonics suppression using active power filters.

Selection of a control method and proper topology of harmonic suppression, best suited to particular conditions, requires that advantages, disadvantages and limitations of these devices, which exhibit a very broad range of properties.

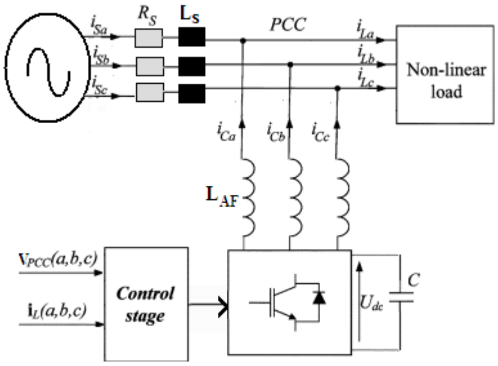


Figure 1: Basic Principal of Shunt Current Compensation in Active Filter

The control strategy for a shunt active power filter generates the reference current, that must be provided by the power filter to compensate reactive power and harmonic currents demanded by the load. This involves a set of currents in the phase domain, which will be tracked generating the switching signals applied to the electronic converter by means of the appropriate closed-loop switching control technique such as hysteresis or deadbeat control. Several methods including instantaneous real and reactive power theory have been proposed for extracting the harmonic content [2-5]. With the development of power electronic technology, low voltage and high current switching power supply has been applied widely in production and life. But harmonic pollution becomes severe increasingly in switching power supply. Generally, there are two methods to eliminate harmonics, which are mainly passive power filter and active power filter. The former is relatively low cost, but filtering effect is far from desirability. By contrast, the latter can suppress the harmonics instantly and compensate reactive power, and it becomes an effective approach to inhibit harmonics. Thus, this paper employs active power filter to suppress harmonic current of low voltage and high current switching power supply.

DESIGN OF APF

Principle of APF

A APF, which is schematically depicted in Figure 2, consists of a two-level Voltage Source Converter (VSC), a dc energy storage device, a coupling transformer connected in shunt to the distribution network through a coupling transformer. The VSC converts the dc voltage across the storage device into a set of three-phase ac output voltages. These voltages are in phase and coupled with the ac system through the reactance of the coupling transformer. Suitable adjustment of the phase and magnitude of the APF output voltages allows effective control of active and reactive power exchanges between the APF and the ac system. Such configuration allows the device to absorb or generate controllable active and reactive power.

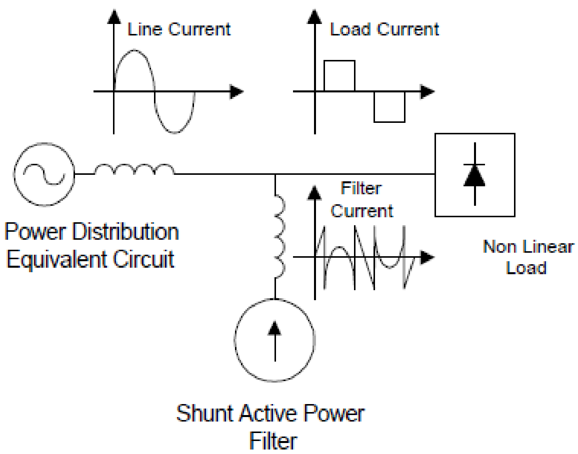


Figure 2: Schematic Diagram of a APF

The VSC connected in shunt with the ac system provides a multifunctional topology which can be used for up to three quite distinct purposes:

- Voltage regulation and compensation of reactive power;
- Correction of power factor
- Elimination of current harmonics.

Here, such device is employed to provide continuous voltage regulation using an indirectly controlled converter. As shown in Figure.-1 the shunt injected current I_{sh} corrects the voltage sag by adjusting the voltage drop across the system impedance Z_{th}. The value of I_{sh} can be controlled by adjusting the output voltage of the converter. The shunt injected current I_{sh} can be written as,

$$I_{sh} = I_L – I_S = I_L – (V_{th} – V_L) / Z_{th} \quad (1)$$

$$I_{sh} /\_\eta = I_L /\_- \theta \quad (2)$$

It may be mentioned that the effectiveness of the APF in correcting voltage sag depends on the value of Z_{th} or fault level of the load bus. When the shunt injected current I_{sh} is kept in quadrature with V_L, the desired voltage correction can be achieved without injecting any active power into the system. On the other hand, when the value of I_{sh} is minimized, the same voltage correction can be achieved with minimum apparent power injection into the system.

Principle of APF Applied to Drive

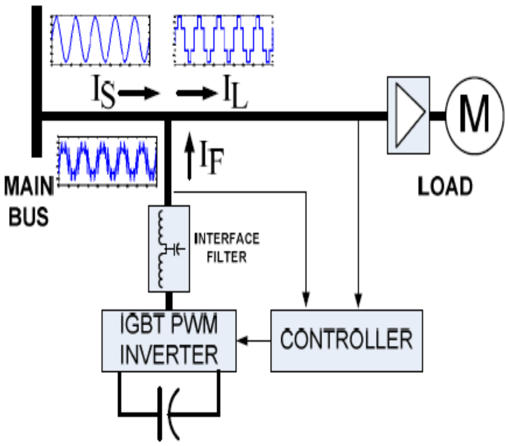


Figure 3: Schematic Diagram of a APF

An active power filter, APF, typically consists of a three phase pulse width modulation (PWM) voltage source inverter [5]. When this equipment is connected in series to the ac source impedance it is possible to improve the compensation characteristics of the passive filters in parallel connection [6], [7]. This topology is shown in Figure 3, where the active filter is represented by a controlled source, where is the voltage that the inverter should generate to achieve the objective of the proposed control algorithm.

Instantaeous Power Theory

The control scheme of the shunt active power filter must calculate the current reference signals from each phase of the inverter using instantaneous real-power compensator. The block diagram as shown in Figure.4, that control scheme generates the reference current required to compensate the load current harmonics and reactive power. The PI controller is tried to maintain the dc-bus voltage across the capacitor constant of the cascaded inverter. This instantaneous real- power

compensator with PI-controller is used to extracts reference value of current to be compensated.

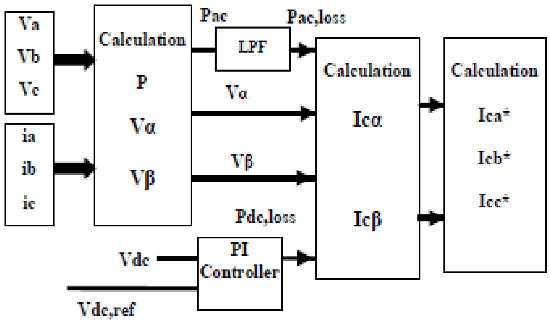


Figure 4: Reference Current Generator Using Instantaneous Real-Power Theory

These reference currents *isa**,*isb *and isc* * are calculated instantaneously without any time delay by using the instantaneous α,β coordinate currents. The required references current derivate from the inverse Clarke transformation and it can be written as

$$\begin{pmatrix} i_{sa}^{*} \\ i_{sb}^{*} \\ i_{sc}^{*} \end{pmatrix} = \sqrt{\frac{2}{3}} \begin{pmatrix} 1 & 0 \\ \frac{-1}{2} & \frac{\sqrt{3}}{2} \\ \frac{-1}{2} & \frac{-\sqrt{3}}{2} \end{pmatrix} \begin{pmatrix} i_{c\alpha} \\ i_{c\beta} \end{pmatrix} \tag{1}$$

The reference currents (*isa**, *isb * and isc **) are compared with actual source current (is)*isa* , *isb and isc* that facilitates generating cascaded multilevel inverter switching signals using the proposed triangular-sampling current modulator. The small amount of real-power is adjusted by changing the amplitude of fundamental component of reference currents and the objective of this algorithm is to compensate all undesirable components. When the power system voltages are balanced and sinusoidal, it leads to constant power at the dc bus capacitor and balanced sinusoidal currents at AC mains simultaneously.

PROPOSED INSTANTANEOUS PROPOSED CONCEPT

The proposed instantaneous real-power (p) theory derives from the conventional p-q theory or instantaneous power theory concept and uses simple algebraic calculations. It operates in steady-state or transient as well as for generic voltage and current power systems that allowing to control the active power filters in real-time. The active filter should supply the oscillating portion of the instantaneous active current of the load and hence makes source current sinusoidal.

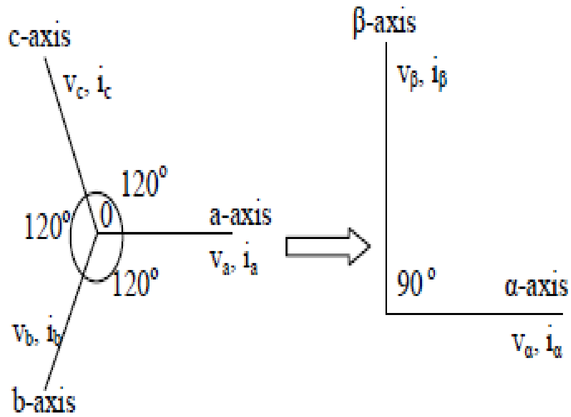


Figure 5: α-β Coordinates Transformation

The p-q theory performs a Clarke transformation of a stationary system of coordinates *a b c* to an orthogonal reference system of coordinates α ,β . In *a b c* coordinates axes are fixed on the same plane, apart from each other by 120o that as shown in Figure 5. The instantaneous space vectors voltage and current *Va* , *ia* are set on the a-axis, *Vb* , *ib* are on the b axis, and *Vc* , *ic* are on the c axis. These space vectors are easily transformed into α ,β coordinates. The instantaneous source voltages *vsa*, *vsb*, *vsc* are transformed into the α ,β coordinate's voltage *v*〈 , *v*® by Clarke transformation as follows:

$$\begin{pmatrix} v_\alpha \\ v_\beta \end{pmatrix} = \sqrt{\frac{2}{3}} \begin{pmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{pmatrix} \begin{pmatrix} v_{sa} \\ v_{sb} \\ v_{sc} \end{pmatrix} \tag{2}$$

Similarly, the instantaneous source current *isa*, *isb*, *isc* also transformed into the α ,β coordinate's current *i* α , *i* β by Clarke transformation that is given as;

$$\begin{pmatrix} i_\alpha \\ i_\beta \end{pmatrix} = \sqrt{\frac{2}{3}} \begin{pmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{pmatrix} \begin{pmatrix} i_{sa} \\ i_{sb} \\ i_{sc} \end{pmatrix} \tag{3}$$

Where α and βaxes are the orthogonal coordinates. They *V*α , *i*α are on the α-axis, and *V*β , *i*β are on the β-axis.

Real-Power (p) Calculation

The orthogonal coordinates of voltage and current *v*α ,*i*α are on theα -axis and *v*β , *i*β are on theβ -axis. Let the instantaneous real-power calculated from the α -axis and β - axis of the current and voltage respectively. These are given by the conventional definition of real-power as :

$$p_{ac} = v_\alpha \ i_\alpha + v_\beta \ i_\beta \tag{4}$$

This instantaneous real-power □*pac* is passed to first order Butterworth design based 50 Hz low pass filter (LPF) for eliminating the higher order components; it allows the fundamental component only. These LPF indicates ac components of the real-power losses and it's denoted as *pac*

The DC power loss is calculated from the comparison of the dc-bus capacitor voltage of the cascaded inverter and desired reference voltage. The proportional and integral gains (PI Controller) are determining the dynamic response and settling time of the dc-bus capacitor voltage. The DC component power losses can be written as

$$p_{DC(loss)} = \left[v_{DC,ref} - v_{DC} \right] \left[k_P + \frac{k_I}{s} \right] \tag{5}$$

The instantaneous real-power (*p*) is calculated from the AC component of the real-power loss *pac* and the DC power loss *pDC*(*Loss*)) ; it can be defined as follows;

$$p = \overline{p_{ac}} + p_{DC(Loss)} \tag{6}$$

The instantaneous current on the $\alpha\beta$ coordinates of *Ic*α *and ic*β are divided into two kinds of instantaneous current components; first is real-power losses and second is reactive power losses, but this proposed controller computes

only the real-power losses. So the α,β coordinate currents $ic\alpha$,$ic\beta$ are calculated from the $v\alpha$,$v\beta$ voltages with instantaneous real power p only and the reactive power q is assumed to be zero. This approach reduces the calculations and shows better performance than the conventional methods. The α,β coordinate currents can be calculated as

$$\begin{pmatrix} i_{c\alpha} \\ i_{c\beta} \end{pmatrix} = \frac{1}{v_\alpha^{\,2} + v_\beta^{\,2}} \left\{ \begin{pmatrix} v_\alpha & v_\beta \\ v_\beta & -v_\alpha \end{pmatrix} \begin{pmatrix} p \\ 0 \end{pmatrix} \right\} \tag{7}$$

From this equation, we can calculate the orthogonal coordinate's active-power current. The α –axis of the instantaneous active current is written as:

$$i_{\alpha p} = \frac{v_\alpha p}{v_\alpha^{\,2} + v_\beta^{\,2}} \tag{8}$$

Similarly, the β -axis of the instantaneous active current is

Written as:

$$i_{\beta p} = \frac{v_\beta p}{v_\alpha^{\,2} + v_\beta^{\,2}} \tag{9}$$

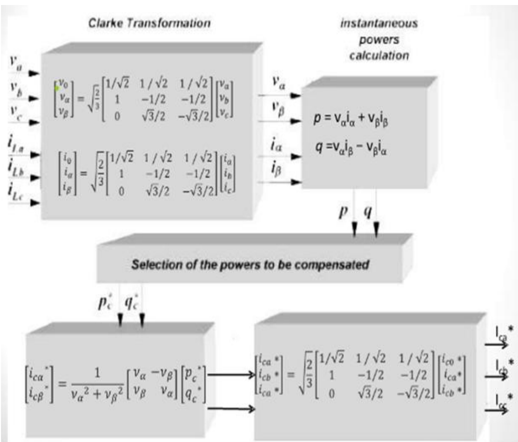
Let the instantaneous powers $p(t)$ in the α -axis and the β - axis is represented as *p*〈 and *p*® respectively. They are given by the definition of real-power as follows:

$$p(t) = v_{\alpha p}(t)\; i_{\alpha p}(t) + v_{\beta p}(t)\; i_{\beta p}(t) \tag{10}$$

From this equation (10), substitute the orthogonal coordinates α -axis active power (8) and β –axis active power (8); we can calculate the real-power $p(t)$ as follows

$$p(t) = v_\alpha(t)\left(\frac{v_\alpha p}{v_\alpha^{\,2} + v_\beta^{\,2}}\right) + v_\beta(t)\left(\frac{v_\beta p}{v_\alpha^{\,2} + v_\beta^{\,2}}\right) \tag{11}$$

The AC and DC component of the instantaneous power $p(t)$ is related to the harmonics currents. The instantaneous real power generates the reference currents required to compensate the distorted line current harmonics and reactive power.



MATLAB/SIMULINK MODELING AND SIMULATION RESULTS

Here Simulation is carried out for two cases. 1. Design of Active Power Filter for Low Voltage and High Current Switching technique. 2. APF is driving a linear load with balanced & unbalanced system. 3. APF is driving a non linear load with balanced & unbalanced system. 4. APF is driving a variable load with balanced & unbalanced system.

Case 1: Design of Active Power Filter for Low Voltage and High Current Switching technique

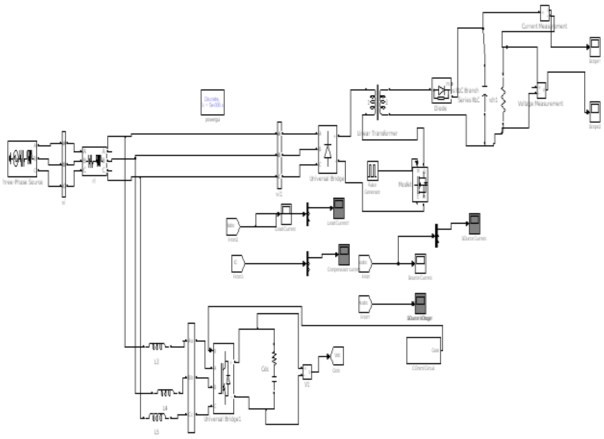


Figure 6: Matlab/Simulink Power Circuit Model of APF

Figure 7 shows the three phase source voltages, three phase source currents and load currents respectively without APF. It is clear that without APF load current and source currents are same.

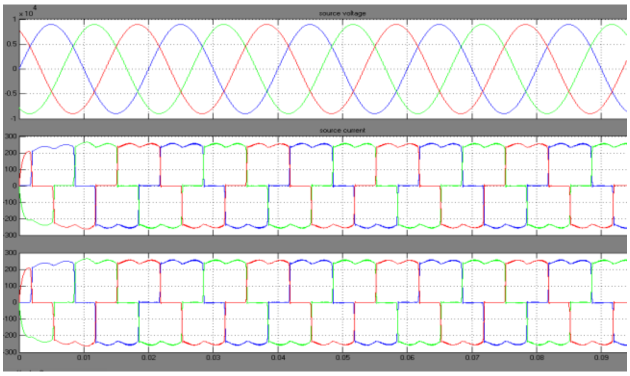
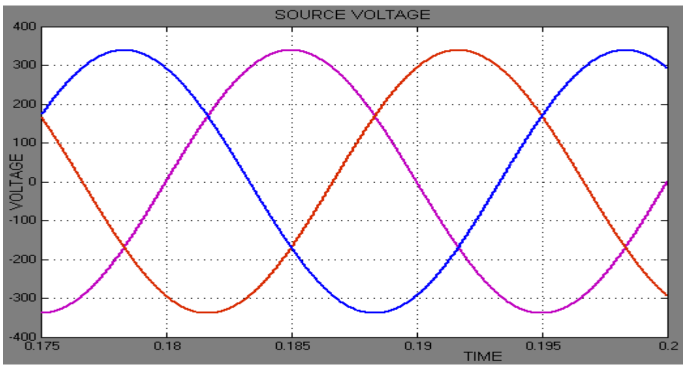
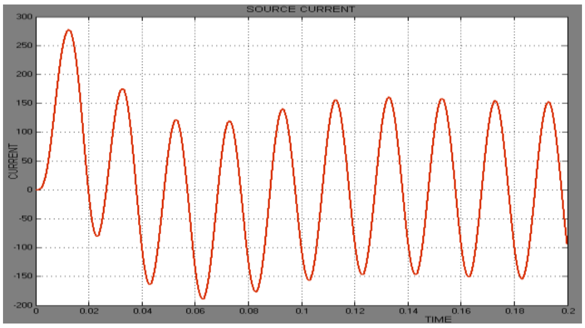


Figure 7: Source Voltage, Current and Load Current without APF

Figure 8 shows the three phase source voltages, three phase source currents and load currents respectively with APF. It is clear that with APF even though load current is non sinusoidal source currents are sinusoidal.



(a)



(b)

(c)

Figure 8: Source Voltage, Current and Load Current with APF

Figure 9 shows the harmonic spectrum of Phase –A Source current with APF. The THD of source current with APF is 3.21%

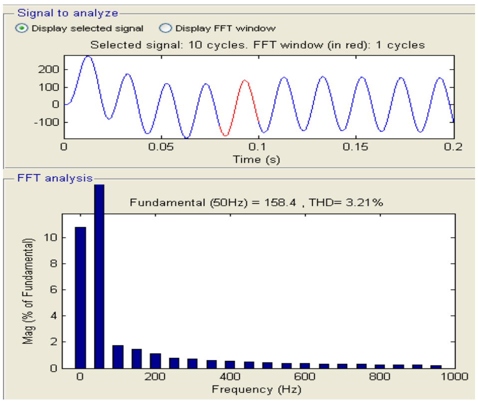


Figure 9: Harmonic Spectrum of Phase-A Source Current with APF

Case 2: APF is Driving a Linear Load with Balanced & Unbalanced System

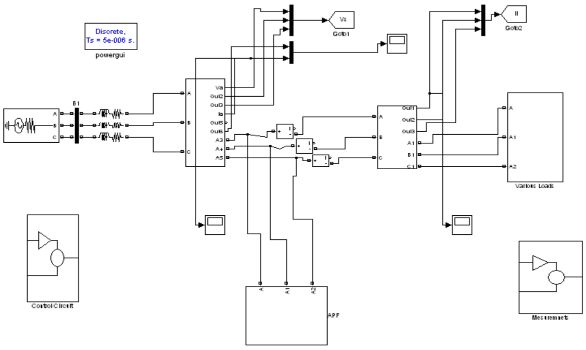


Figure 10: Matlab/Simulink Model of APF with Linear Balanced Load

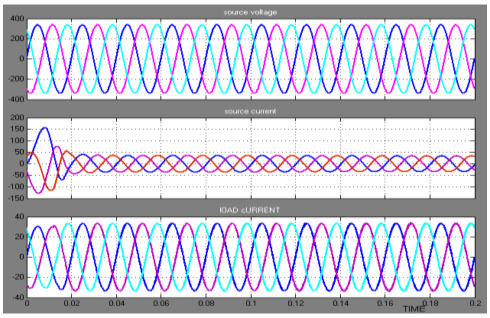


Figure 11: Simulation Results of APF with Linear Balanced Load

Figure 11 shows the three phase source voltages, three phase source currents and load currents respectively with APF.

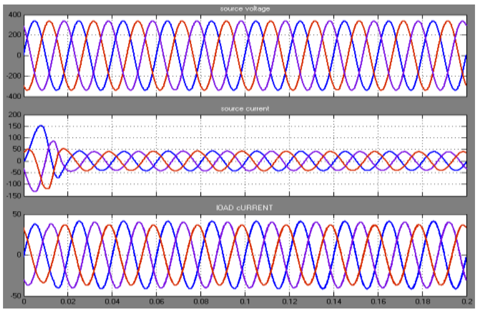


Figure 12: Simulation Results of APF with Linear Unbalanced Load

Figure 12 shows the three phase source voltages, three phase source currents and load currents respectively with APF. Here load current magnitudes are different.

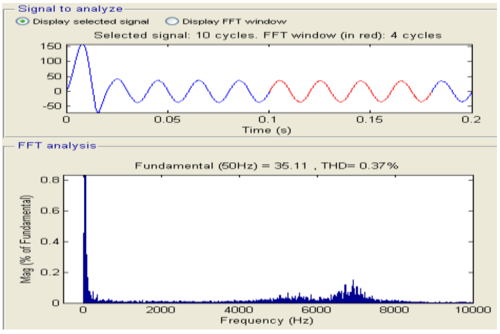


Figure 13: THD Analysis of Source Current with APF with Balanced Linear Load

Figure 13 THD analysis of source current with APF with balanced linear load, THD is 0.37%.

Case 3: APF is driving a non linear load with balanced & unbalanced system.

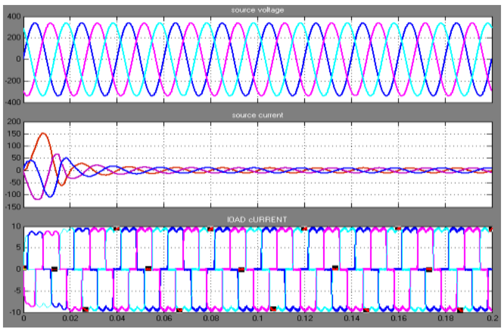


Figure 14: Simulation Results of APF with Non Linear Balanced Load

Figure 14 shows the three phase source voltages, three phase source currents and load currents respectively with nonlinear balanced APF.

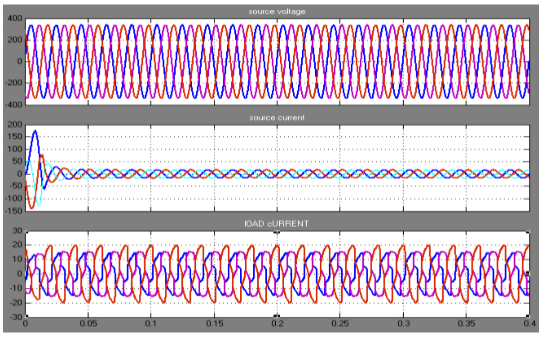


Figure 15: Simulation Results of APF with Non Linear Unbalanced Load

Figure 15 shows the three phase source voltages, three phase source currents and load currents respectively with APF. Here load current magnitudes are different.

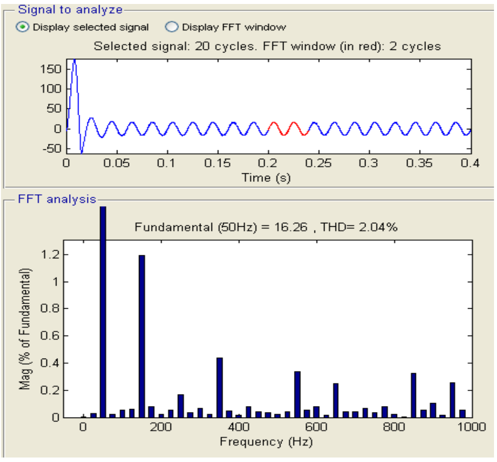


Figure 16: THD Analysis of Source Current with APF with Balanced Linear Load

Figure 16 shows the THD analysis of source current with APF with balanced linear load, THD is 2.04%.

Case 4*: APF is driving a variable load with balanced & unbalanced system:*

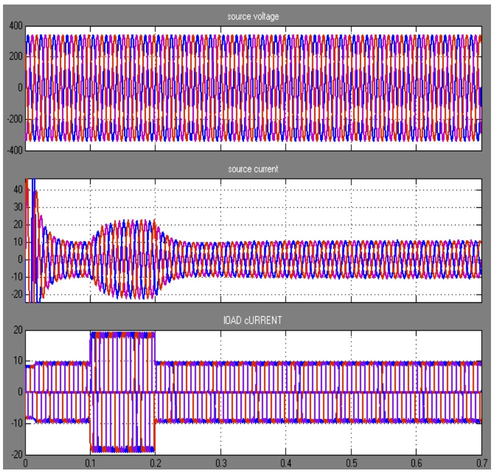


Figure 17: Simulation Results of APF with Variable Balanced Load.

Figure 17 Shows the Simulation results of APF with variable balanced load, three phase source voltages, three phase source currents and load currents respectively with variable balanced APF.

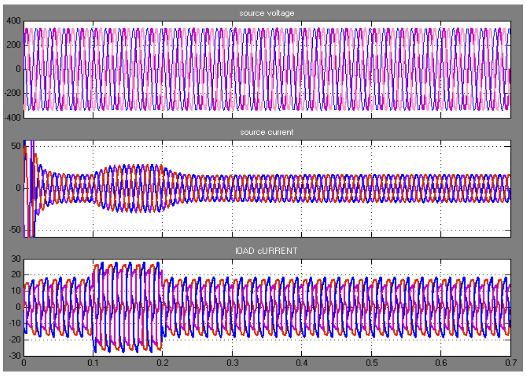


Figure 18: Simulation Results of APF with Variable Unbalanced Load

Figure 18 Shows the Simulation results of APF with variable unbalanced load, three phase source voltages, three phase source currents and load currents respectively with variable unbalanced APF.

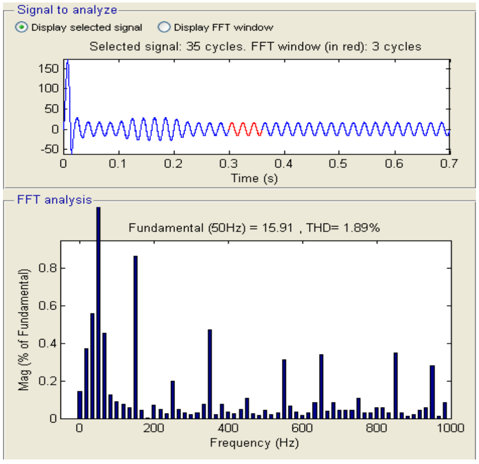


Figure 19: THD Analysis of Source Current with APF with Variable Balanced Load

Figure 19 shows the THD analysis of source current with APF with variable balanced load, THD is 1.89%.

CONCLUSIONS

This paper analyzes harmonics in switching power supply of low voltage and high current and designs active power filter to suppress the harmonic current and same proposed concept applied to various loads such as linear load, nonlinear load, variable load, both balanced & unbalanced type. Not only introduce operating principle and parameter design comprehensively, but also verify the filtering effect via constructing the simulation module on the platform of Matlab/Simulink. The simulation results show harmonic current of low voltage and high current switching power supply can be inhibited instantaneously, and the active power filter has the nice performance of compensating harmonics. THD analysis are nearly less than 5%, as per IEC standards.

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AUTHOR’S DETAILS

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Dileep Kishan Udattu is pursuing his final year B.Tech in Electrical and Electronic Engineering from CVR College of Engineering, Hyderabad. He is interested to pursue higher studies in USA. He is interested in Electrical Machines and power systems. Power quality is the main area of research.